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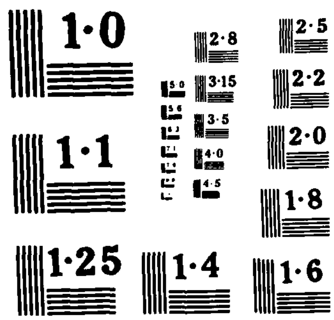

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MEMORANDUM REPORT BRL-MR-3481

GASDYNAMIC QUANTITIES ABOUT RAMJET PROJECTILE WHILE IN TRANSITIONAL BALLISTICS REGION

Kevin S. Fansler

November 1985

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (ner)

A study was performed to determine whether the fins of a ramjet projectile are deployed in the reverse flow of the gun blast with adverse consequences. Two muzzle blast simulation schemes were utilized to compute the flow quantities about the rear of the projectile. An estimate of the pressures internal to the projectile was also made because the deployment process for the fins depends upon the relative pressures internal and external to the projectile pusher plate. The calculations show that the deployment process starts before the base of the projectile leaves the jet plume or reverse flow re-

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gion. Nevertheless, the impulse given the pusher plate, which deploys the fins, is so small that the fins do not move back far enough for the reverse flow to harm them. The study sponsor was the Advanced Munitions Branch, Applied Science Divsion, Large Caliber Weapon Systems Laboratory, Armament Research & Development Center.

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I. INTRODUCTION

A ramjet-assisted round is under consideration that can reach and maintain velocities that will permit extended range applications. The round is stabilized by segmented sleeve flare fins that deploy after it is launched. It is particularly important that these fins should not deploy in an unfavorable position in the muzzle blast region.

Figure 1 is a schematic of the muzzle blast region after the obturator has cleared the muzzle. The propellant gases exiting from the muzzle expand and accelerate within the jet core until they reach the recompression shocks. Within the core, the gasdynamic properties are almost steady and depend upon the muzzle-exit gasdynamic properties. Figure 2 shows the gasdynamic properties along the centerline for the jet-plume region of an underexpanded steady jet flow. The jet exit Mach numbers for the ramjet-assisted projectiles have values near 1.5; thus, the centerline properties do not change with distance until the head of the rarefaction wave emanating from the tube corner reaches the centerline. Once this occurs, the pressure along the centerline rapidly falls off with distance from the muzzle while the flow velocity increases to levels in excess of the projectile launch velocity. Should the fins deploy in this reverse flow region, there is the strong possibility that they would be damaged.

The jet core is terminated at the shock layer, the region between the air-blast front and the Mach disc. Here, the pressure recovers to above atmospheric pressure and the gas within this region moves more slowly than the projectile. If the fins deploy in the shock layer, the force on the fins will be as for normal flight.

We want to determine the gasdynamic quantities around the projectile during residence in the muzzle blast. We can thereby design to avoid deployment in a region which might cause damage to the fins. The base of the round consists of a pusher plate which will be discarded after launch. The pusher plate covers the ramjet exhaust. The intake of the ramjet engine is near the front of the projectile. Thus, while the projectile is in the tube, the interior of the projectile pressurizes as the projectile accelerates and compresses the air in front of it. After launch, the pressure internal to the motor relaxes toward the free stream stagnation pressure behind a normal shock. As the projectile traverses through the jet plume, the pressure on the rear of the pusher plate declines. At a certain point, the force on the front of the pusher plate becomes greater than the force on the back of the pusher plate. The unbalanced force can be utilized to deploy the fins or to simply discard the pusher plate if the fins deploy by a separate mechanism.

In this work, the gasdynamic quantities are calculated on the front and the back of the projectile. Two numerical simulation codes are exercised to calculate the quantities at the projectile rear. The first code is an axisymmetric Godunov first-order code[1] modified to simulate typical gun-blast

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1. *G. F. Widhopf, J. C. Buell, and E. M. Schmidt, "Time Dependent Near Field Muzzle Brake Flow Simulations," Proceedings of the AIAA/ASME 3rd Joint Thermo-Physics, Fluids, Plasma and Heat Transfer Conference, AIAA*

problems. This code can only perform the simulation relatively near the muzzle because the number of cells is limited by the computer being used. It is utilized to simulate the flow for projectile travels of less than three calibers. The other code, called DAWNA,[2] is used to determine the flow for the larger distances. Since the original DAWNA code does not asume that there is a projectile in the flow, we assume Newtonian hypersonic theory to obtain the pressure on the rear of the projectile.

II. MODEL

To examine the flow when the base of the projectile is near the muzzle, the inviscid model developed by Widhopf, et al[1] is used. The model solves a conservative form of the unsteady Euler equations using a one-component compressive gas and utilizes Godunov's scheme. By solving Riemann's problem, the fluxes at the cell surfaces are obtained. Boundary conditions are treated using analytic expressions for one-dimensional wave reflections together with the condition that the normal component of the velocity is zero at the boundary. The cells for this study are sized so that there are 11 cells between the bore axis and the radius of the bore. The cell thickness along the bore direction is one-twentieth of a caliber. A special feature of this code is its provision for a moving boundary. When the projectile rear passes a cell boundary immediately above it, a new cell is formed and is coalesced with the cell behind it. At the same time, the back part of the old cell is returned to its former state as a distinct cell. By reordering the sequence by which the wall boundary is moved through the cells, the present author has improved the accuracy with which the fluid quantities are calculated in the cells adjacent to the moving wall. The front of the projectile is not considered in this simulation; rather, the projectile is treated as semi-infinite in extent. The pressure in the projectile will be obtained by some simplifying assumptions.

Table 1 gives some parameters that were used in this study. Two projectile configurations were considered for the bore diameter, D=105mm.

TABLE 1. MUZZLE EXIT CONDITIONS AND PROJECTILE PARAMETERS

	Slowest Projectile	Fastest Projectile
Muzzle pressure (MPa)	57.0	55.4
Muzzle velocity (m/s)	1,220	1,340

As indicated in the Introduction, DAWNA[2] was used to obtain the gasdynamic quantities at large distances. Utilizing DAWNA also affords an

2. *J. Ranlet and J. Erdos, "Description of FORTRAN Program DAWNA of Analysis of Muzzle Blast Field," U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, Contractor Report No. BRLCR-302, April 1976. (AD A024485)*

opportunity to check the results that are generated by the Godunov axisymmetric simulation code. DAWNA is a one-dimensional scheme that simulates the gun-blast flow along the centerline and assumes that the flow is spherically diverging. Formerly, a separate method-of-characteristics[3] code generated the flow quantities in the jet plume along the boreline before DAWNA was run. The present author modeled the flow along the boreline as a spherical source flow with some refinements and used a least-squares fitting procedure to obtain the values of the coefficients for the resulting model equation. The values along the boreline in the the jet plume are now generated as DAWNA is executing. DAWNA yields sharp discontinuities because shocks are fitted instead of being captured. The discontinuity trajectories computed by DAWNA agree well with experiment.

To obtain the pressure on the front of the projectile while in-bore, it is assumed that the projectile travels down the tube at a constant velocity equal to the muzzle-exit value. This assumption yields an upper bound for the pressure inside the projectile and on the front of the pusher plate. Since the base pressure exterior to the pusher plate declines with distance, utilizing this assumed pressure on the pusher-plate front gives a lower bound for the distance at which the pusher plate starts to separate. This in turn yields the most severe condition to be expected for pusher plate discard and fin deployment.

III. RESULTS

The Godunov code[1] is used to obtain pressures on the base and for the cell immediately above and behind the rear of the projectile. Figure 3 gives these results for the fastest projectile. The curves shown are for different distances from the axis. The uppermost curve corresponds to the pressure for the second cell from the axis and is seen to at first increase and then decrease. The pressure should stay constant until the rarefaction wave traveling from the projectile corner reaches the field point. The errant behavior stems from an incorrect treatment of the boundary conditions on the axis. The error propagates to cells further off the axis but decreases with increasing distance from the axis. It is seen that after the rarefaction waves sweep past a point on their way to the axis, the pressures on the base vary considerably with distance from the axis and then tend to coalesce for the larger distances. Results were also calculated for the slowest ramjet projectile and are very similar to Figure 3 in appearance.

Figure 4 gives the pressure as a function of time on the base of the projectile at a point 18.4 mm away from the axis. After the arrival of the rarefaction wave, the pressure rapidly declines. Figure 5 shows the pressure on the side of the projectile, 23.6 mm from the base. Initially, the overpressure is zero; then it climbs steeply as the blast wave overtakes the point of interest and then slowly varies during the limited period for the calcu-

3. *A. R. Vick, E. H. Andrews, J. S. Dennard and C. B. Craidon, "Comparison of Experimental Free-Jet Boundaries with Theoretical Results Obtained with the Method-of-Characteristics," NASA Technical Note D-2327, June 1964. (NRIS N64-23032)*

lation.

Mach contours were also obtained for the muzzle blast fields. Figure 6 shows a sequence of Mach contours for the fast ramjet projectile. Figure 6b shows the Mach contours at 44.2 microseconds. The barrel surface corresponds to the outline of the left rectangle. The rear part of the projectile is portrayed to the right. The interval between Mach contour lines is .2 and the solid curve adjacent to a dotted curve corresponds to the gas flowing at sonic velocity. By 100 microseconds, the recompression shock is forming and becomes more distinct at later times. During the times simulated by the Godunov code, the rear of the projectile is immersed in the jet core and reverse flow occurs over the rear of the projectile. Figure 7 shows similar results for the slowest ramjet assisted round.

The DAWNA code[2] was used for the later times. The larger region for computation necessitates the use of larger cells for the Godunov scheme but the resolution decreases with increasing cell size. Figure 8 shows the discontinuity trajectories obtained with DAWNA for the fastest projectile; the starting conditions are supplied by the Godunov code. The rear of the projectile leaves the region of reverse flow after the projectile travels little more than five calibers from the muzzle. As shown in Figure 9, similar conditions prevail for the slowest ramjet assisted projectile. Figure 2 shows the gasdynamic quantities in the flow along the centerline as a function of projectile base position. The jet core is assumed in DAWNA to be the flow for a steady jet. The centerline properties of the jet core are calculated by an approximation procedure developed from a least squares fit to method-of-characteristics calculation results for steady flow. The flow of interest ranges from the exit tube to the Mach disc. As the projectile rear passes the Mach disc, the fluid velocity declines sharply to less than that possessed by the projectile.

Using this jet flow, we can calculate the base pressure in the reverse flow. We assume that the pressure can be approximated by applying Newton's theory which is applicable to hypersonic theory for blunt bodies. For the fastest ramjet assisted projectile, Figure 10 shows the calculated base pressures for the two codes. It is seen that the Godunov code yields higher pressures; this result is consistent with muzzle brake flow simulations where the calculated pressures for the inner part of brake baffles were higher than the experimental values.[1] Figure 11 shows the base pressure for the slowest ramjet assisted projectile. Again, similar results are obtained.

To get an estimate of where the pusher plate starts separating, we need to compare the base pressure with the internal pressure. Since the maximum internal pressure is that which occurs within the gun bore, a conservative estimate of the separation distance may be developed by neglecting venting after separation and taking the internal pressure as constant at the in-bore value. Landau and Lifshitz[4] show

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4. *L. D. Landau and E. M. Lifshitz, Fluid Mechanics, Pergamon Press, 1959, pp 330-357.*

$$\frac{p_2}{p_\infty} = 1 + \frac{\gamma(\gamma+1)}{4\ c^2_\infty} V_p{}^2 + \frac{\gamma\ V_p}{c_\infty} \sqrt{(1 + \frac{(\gamma+1)^2}{16} \frac{V_p^2}{c_\infty^2})} \tag{1}$$

where

p_2/p_∞ = Pressure of compressed air in bars

V_p = Velocity of projectile

c_∞ = Sound speed in ambient air

γ = Specific heat ratio for air.

Substituting the values for the slow projectile, the pressure ratio is 23.6 bars. For the fast projectile, the pressure ratio is 28.1.

To examine the adequacy of this approximation, consider the time for a rarefaction to propagate from the ramjet inlet, along the internal length of the projectile, to its base. The velocity of the rarefaction wave front is found from

$$V_r{}^2 = [(\gamma-1)\ p_\infty + (\gamma+1)\ p_2] / (2\rho_\infty)$$

$$= [(\gamma-1) + (\gamma+1)\ (p_2/p_\infty)]\ [c^2_\infty/(2\gamma)]\ . \tag{2}$$

Substituting the pressure ratio obtained for the fast projectile, the sound speed is 2.38 times the ambient sound speed. The time for the front of the rarefaction wave to reach from the ramjet inlet to the base region would be approximately 0.7 ms, a larger time than it takes to traverse the jet plume region. The same conclusion can be drawn about the slowest projectile.

Figure 12 shows the base pressure and the upper bound internal pressure as a function of time for the slowest ramjet assisted projectile. The upper bound internal pressure exceeds the base pressure for slightly more than 0.2 mseconds. An idea of the movement of the base and fins relative to the projectile can be obtained by making some plausible order-of-magnitude suppositions. Suppose the pusher plate were 1 cm thick and the specific weight of the material were 3. Furthermore, suppose that the net pressure during this interval is 10 bar. Then neglecting the mass of the fins and any friction, the pusher plate velocity relative to the projectile is calculated to be

approximately 20 m/s after 0.2 ms. The total movement rearward would be approximately 7 mm. During this time the fins would be approximately aligned with the flow even if the fins had also moved back 7 mm. The net forces on the fin would be expected to be small.

IV. SUMMARY AND CONCLUSIONS

Using two numerical schemes, we calculate the fluid dynamic quantities on the base of the projectile. We then compare the pressure on the exterior of the pusher plate with the upper bound pressure on the pusher plate interior to the projectile in the jet plume region. Considering the problem of a piston traveling with constant velocity in a tube, we find an upper bound value for the interior pressure. In the region where the assumed internal pressure is greater than the external base pressure, it is possible for the fins to deploy while the pusher plate is discarding. Nevertheless, the time interval for the pusher plate discard process to occur in the jet plume region is so small that with the pressure differences expected, the fins would not have the opportunity to deploy to the extent that they would be vulnerable to damage.

ACKNOWLEDGMENT

I would like to thank Mr. Steven Defeo of the Advanced Munitions Branch, Applied Science Division, Large Caliber Weapon Systems Laboratory, Armament Research & Development Center, for his support and help in this work.

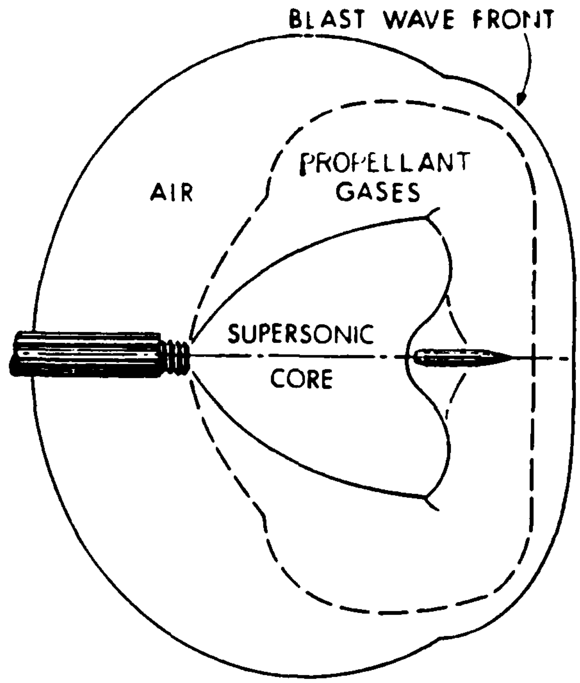


Figure 1. Schematic of Gun Muzzle Blast.

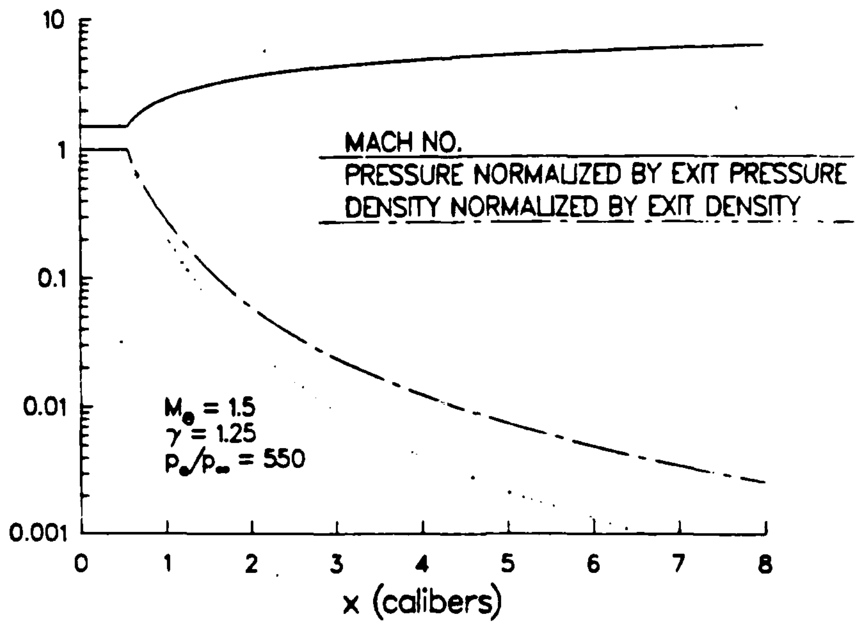


Figure 2. Gasdynamic Properties Along Centerline for Steady Jet Flow.

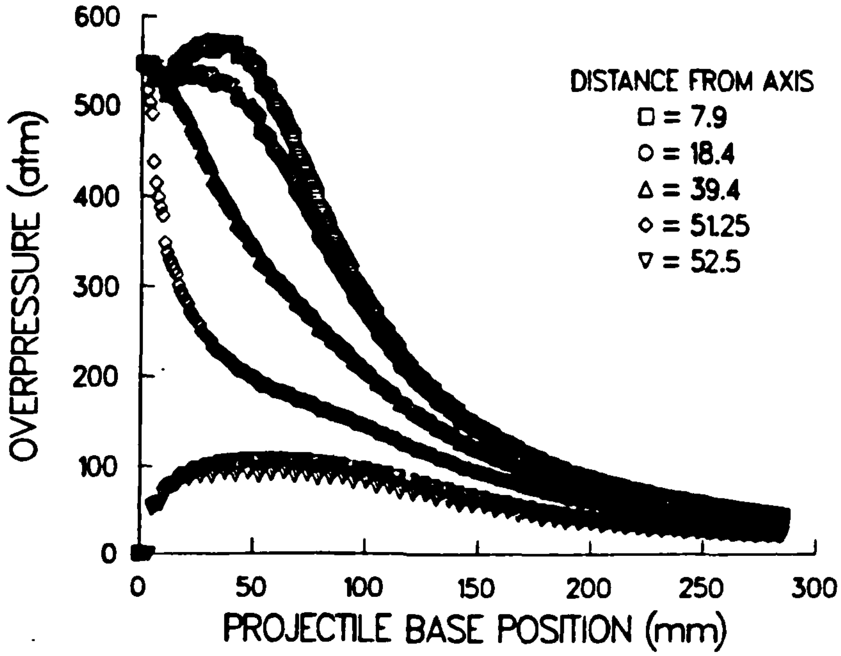


Figure 3. Overpressure vs Projectile-Base Position for Fastest Projectile.

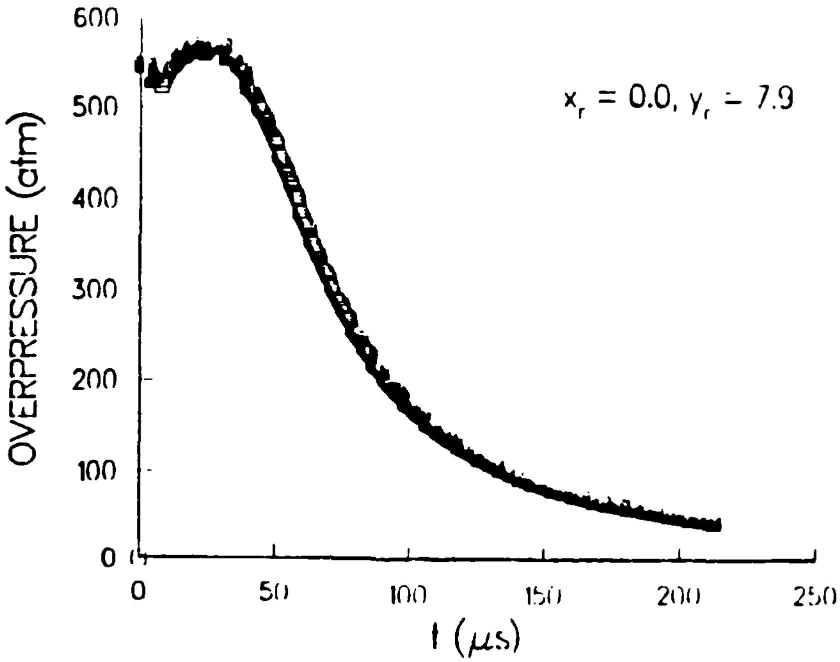


Figure 4. Overpressure vs Time After Exiting the Muzzle for Fastest Projectile.

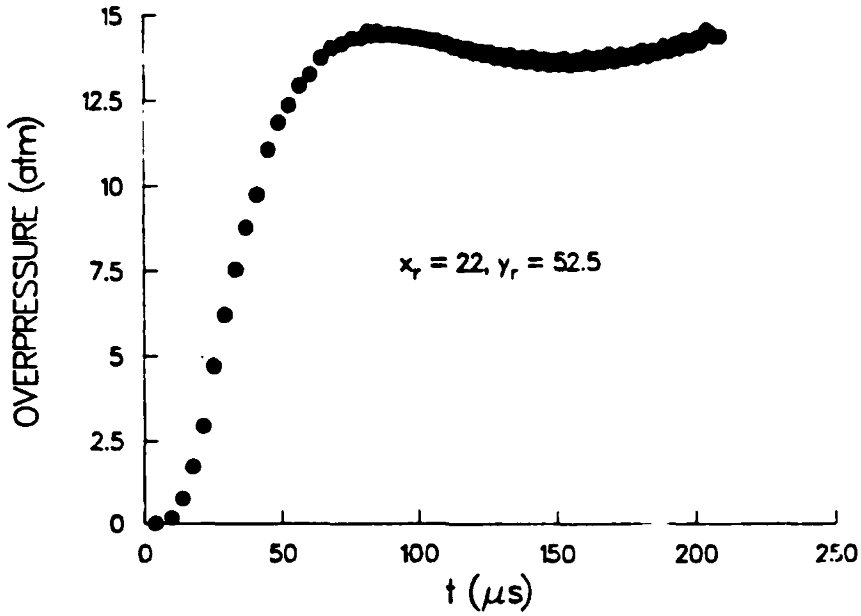
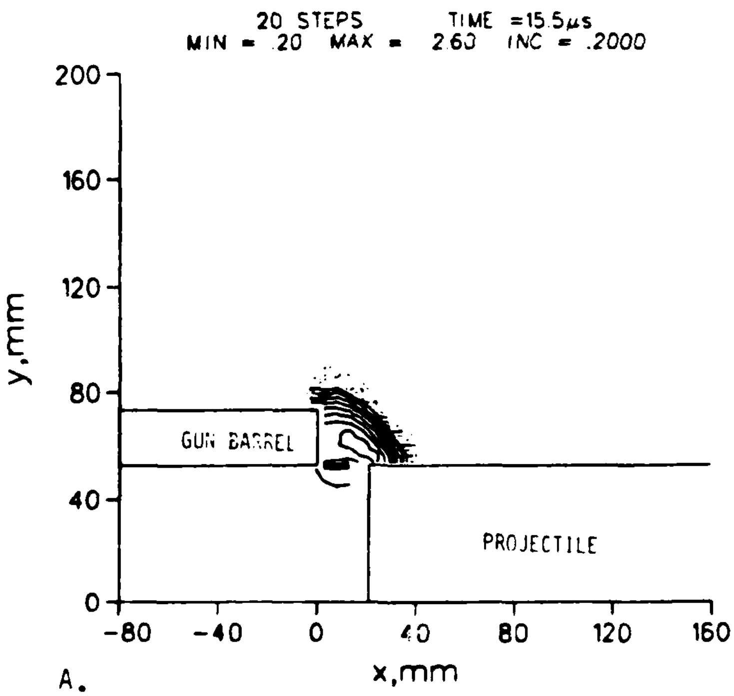
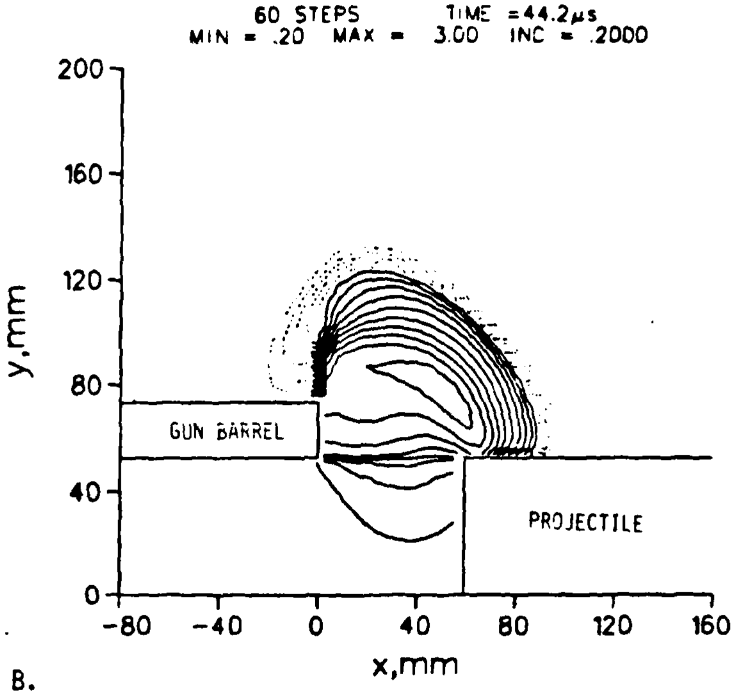


Figure 5. Overpressure at a Location on the Projectile Side.



A.

Figure 6 Mach Contours for Various Times After Muzzle Exit--Fastest Projectile



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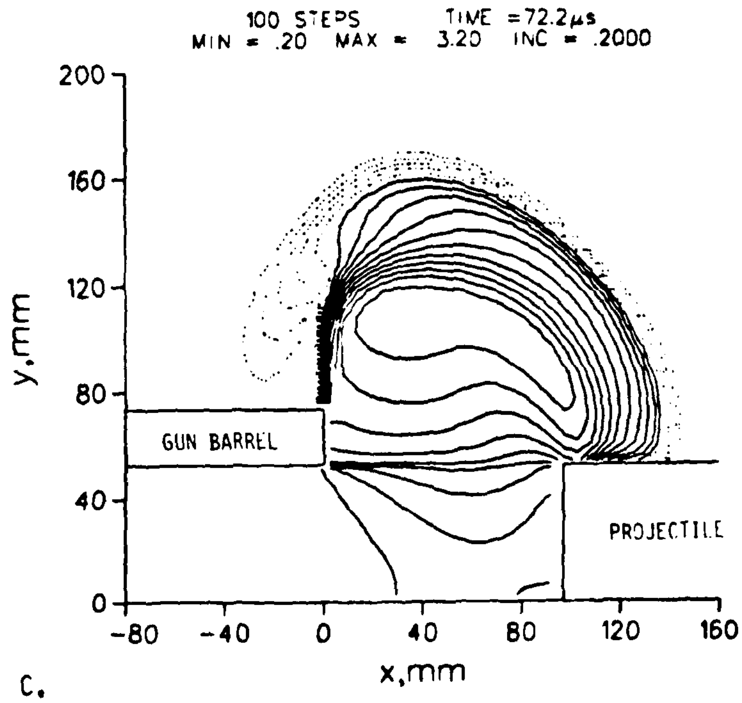

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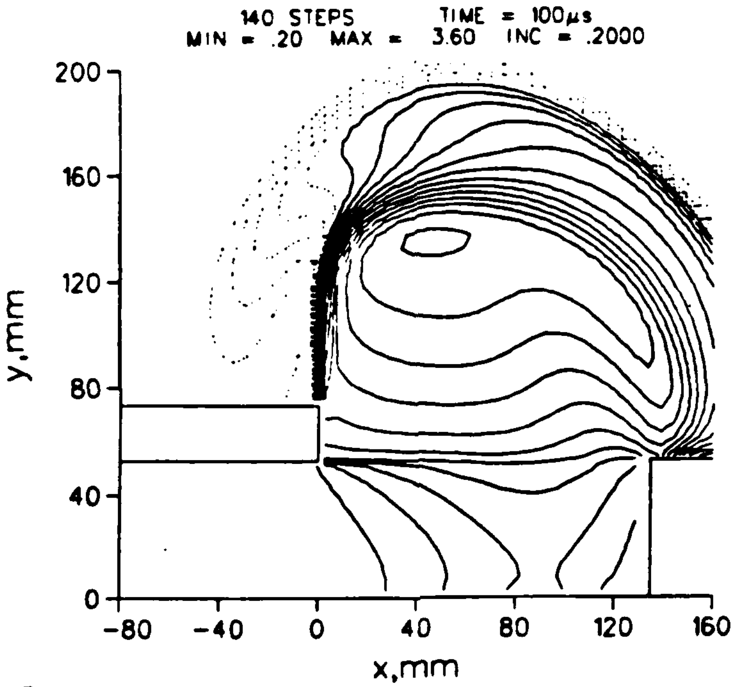
Figure 6. Mach Contours for Various Times After Muzzle Exit--Fastest Projectile (Continued)



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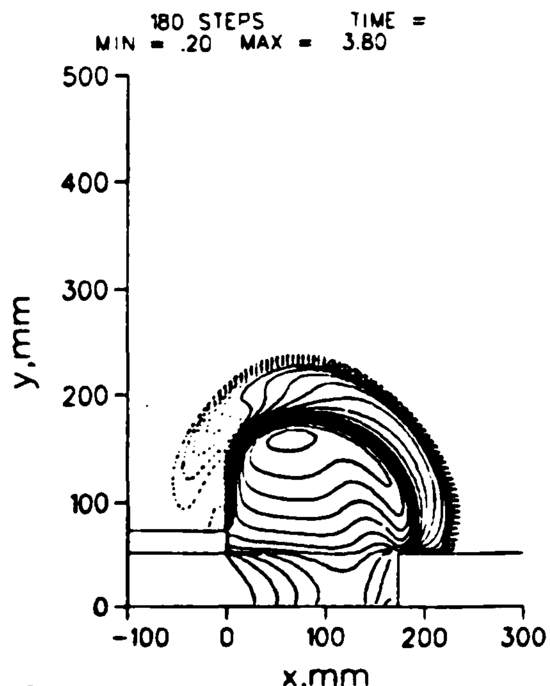

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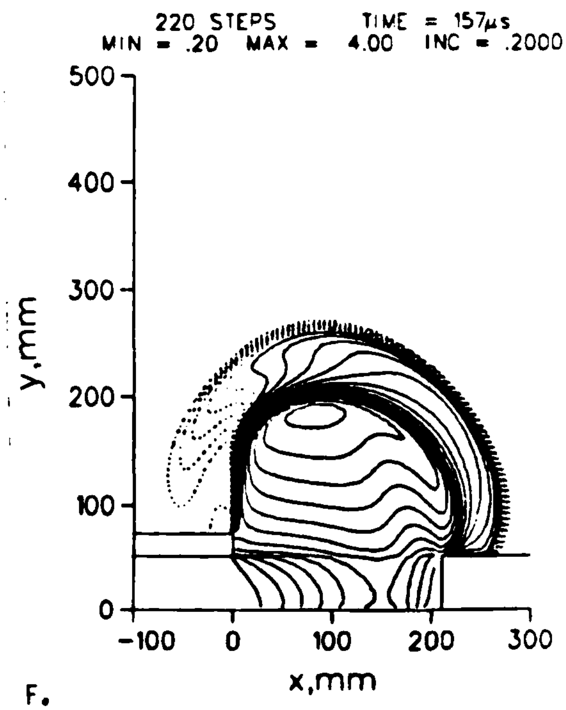

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Figure 6. Mach Contours for Various Times After Muzzle Exit--Fastest Projectile (Continued)

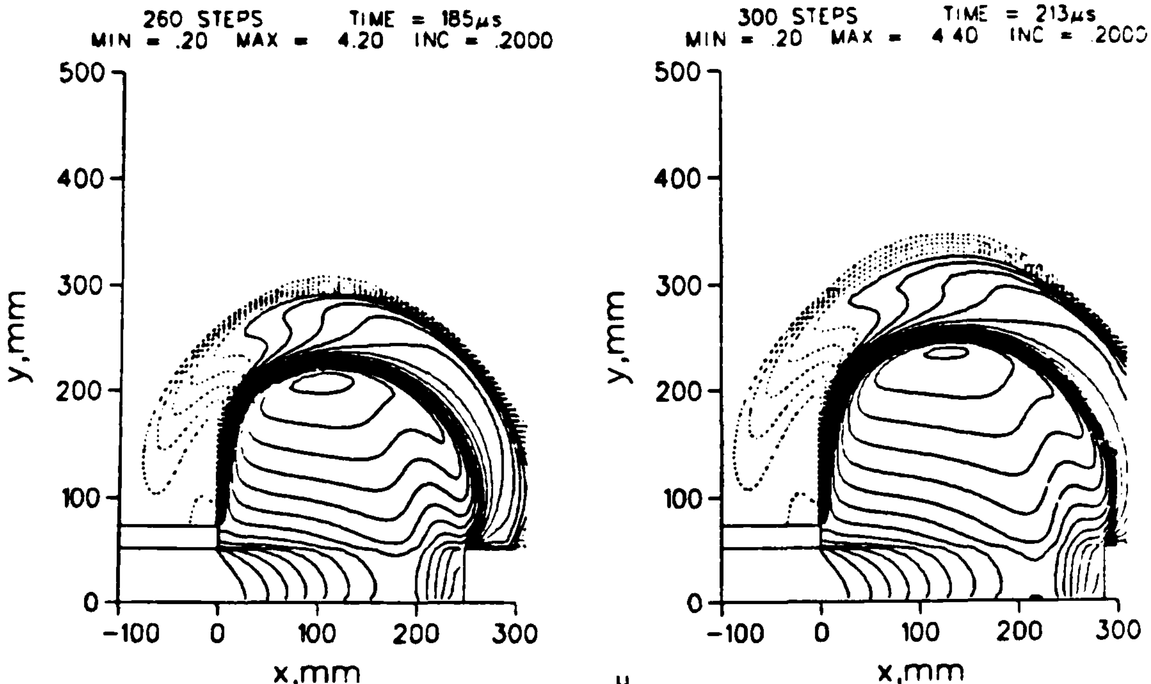

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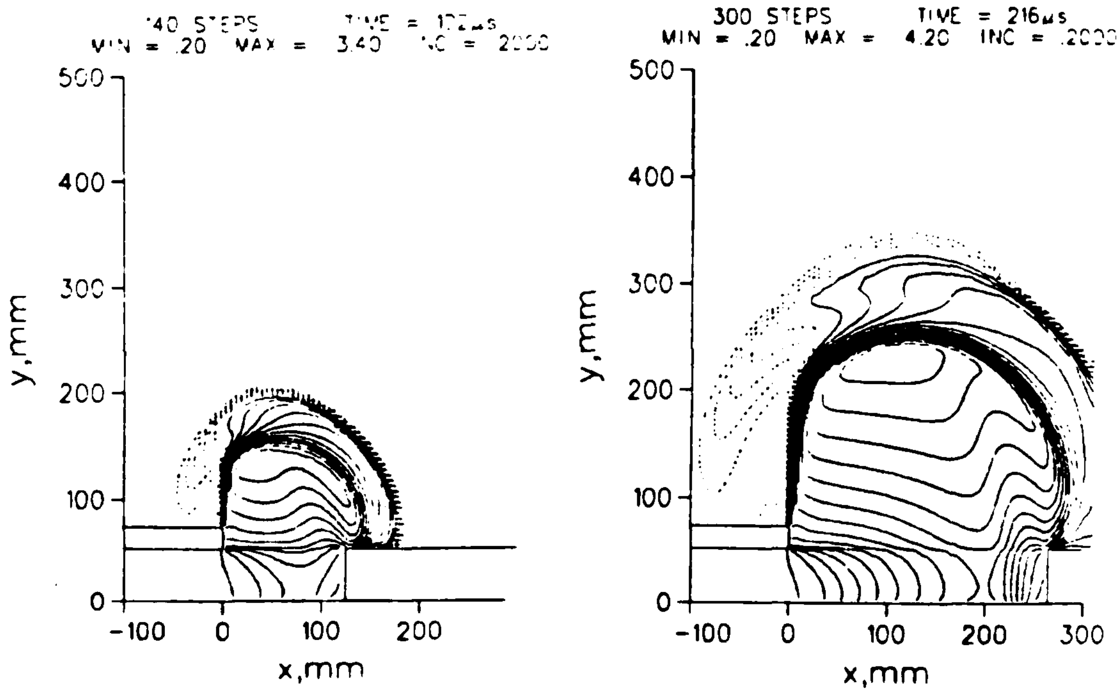
Figure 6. Mach Contours for Various Times After Muzzle Exit--Fastest Projectile (Continued)



A. B.

Figure 7. Mach Contours for Various Times After Muzzle Exit -Slowest Projectile

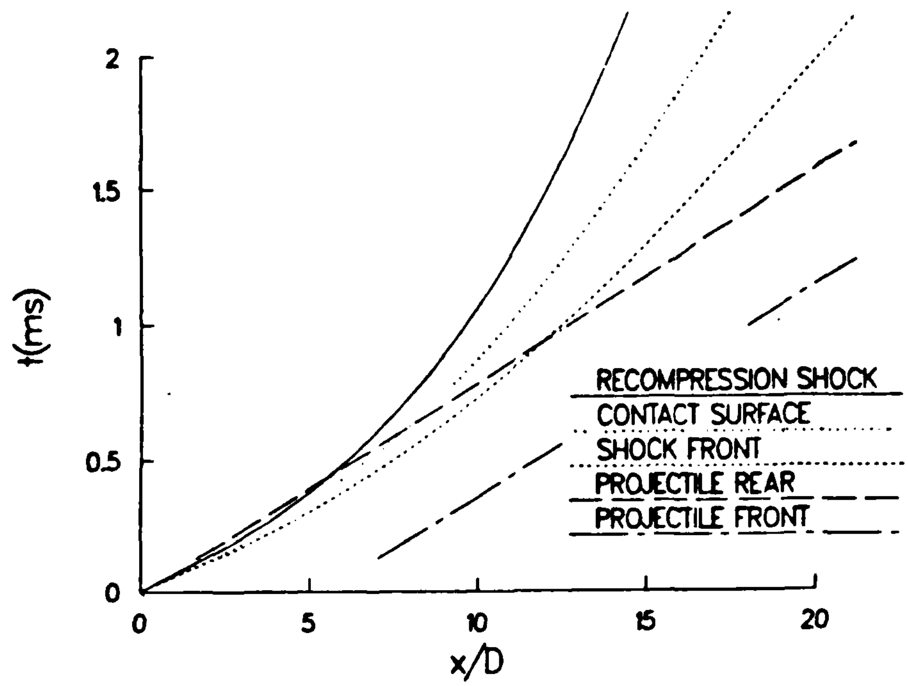


Figure 8. Discontinuity Trajectories for Fastest Projectile.

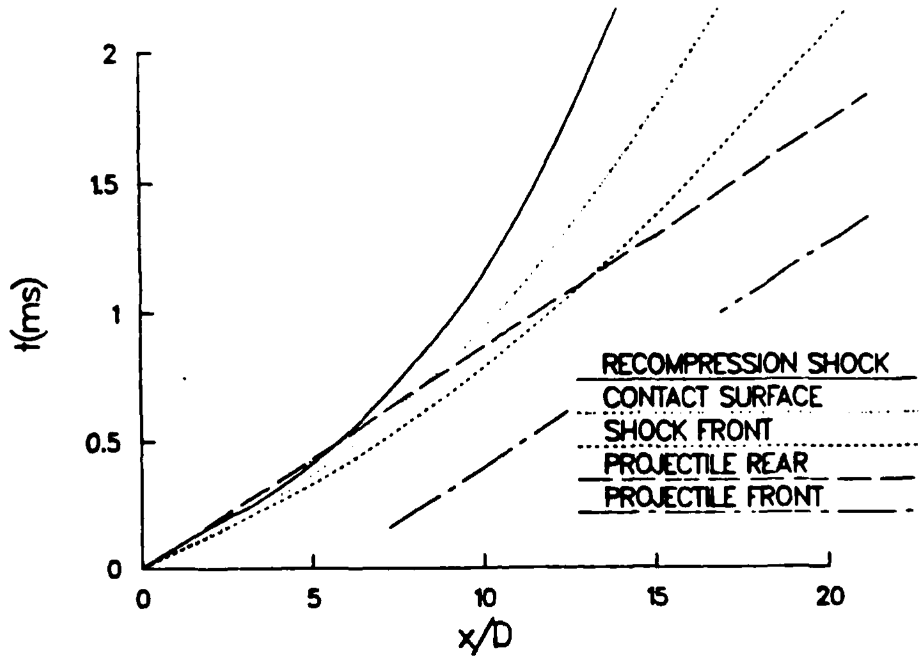


Figure 9. Discontinuity Trajectories for Slowest Projectile.

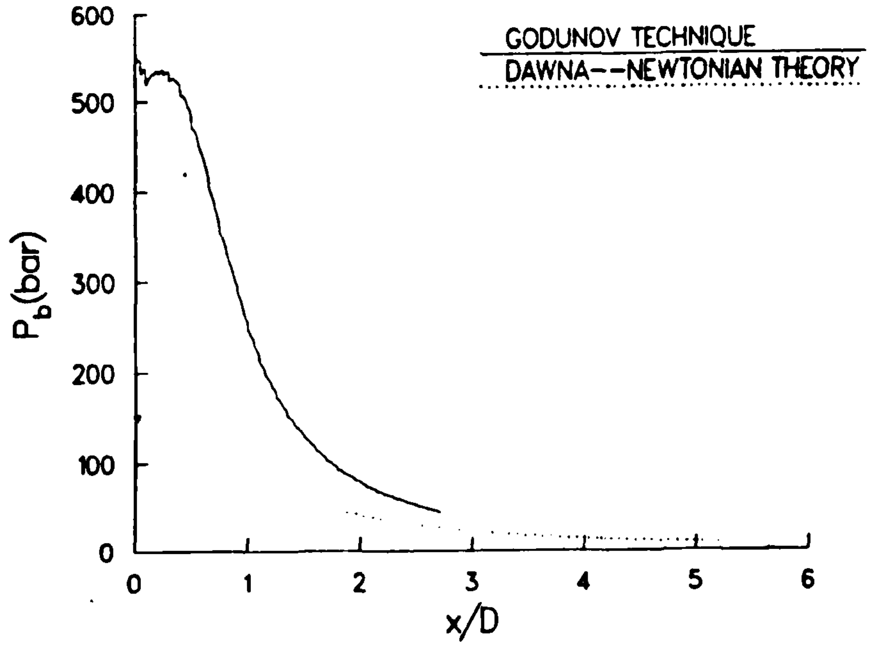


Figure 10. Base Pressure vs Base Position for Fastest Projectile.

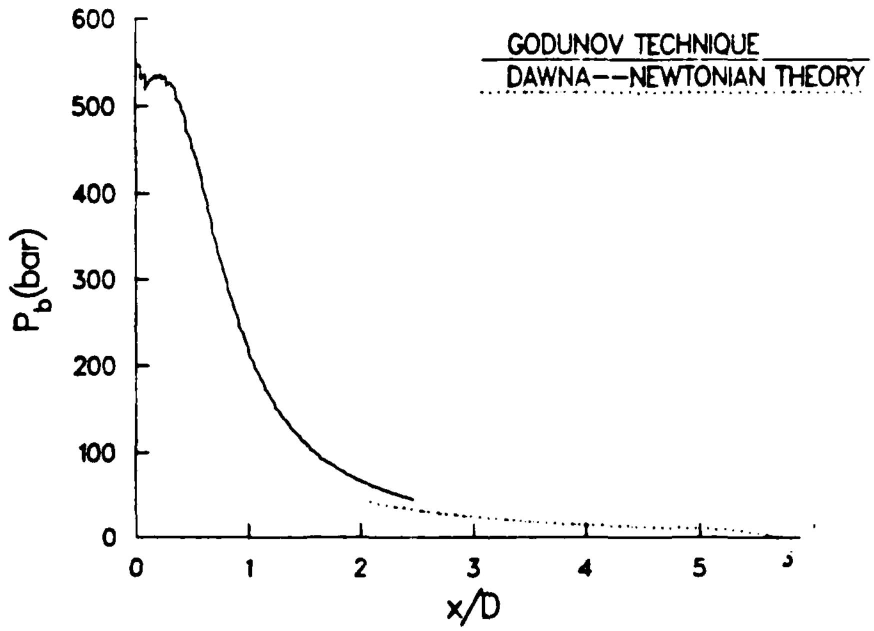


Figure 11. Base Pressure vs Base Position for Slowest Projectile.

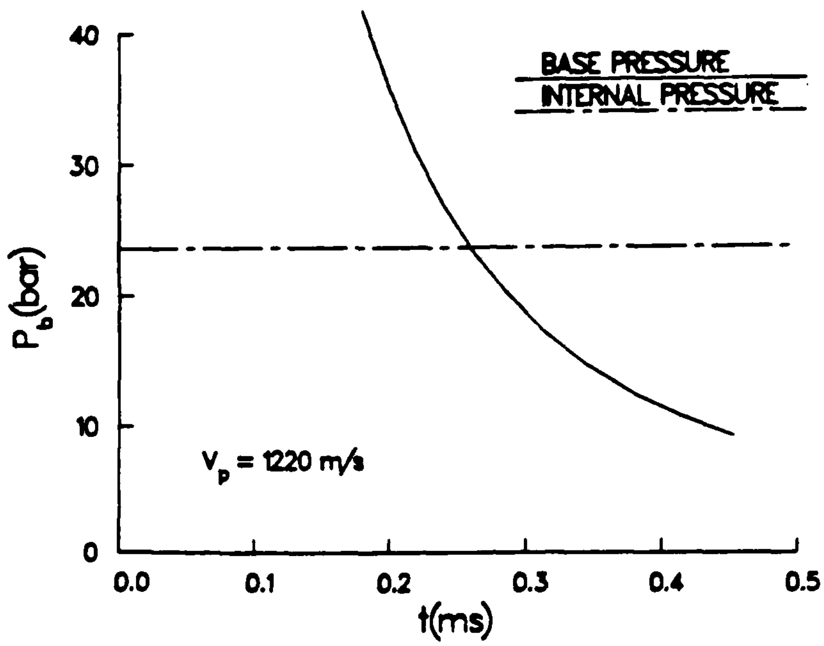


Figure 12. Base Pressure, Obtained From DAWNA Using Newton's Theory, as a Function of Time for Slowest Projectile.

IV. REFERENCES

1. G. F. Widhopf, J. E. Buell, and E. M. Schmidt, "Time-Dependent Near Field Muzzle Brake Flow Simulations," Proceedings of the AIAA/ASME 3rd Joint Thermo-physics, Fluids, Plasma and Heat Transfer Conference, AIAA Paper No. AIAA-82-0973, 7-11 June 1982, St. Louis, Missouri.

2. J. Ranlet and J. Erdos, "Description of FORTRAN Program DAWNA of Analysis of Muzzle Blast Field," U. S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, Contractor Report No. BRLCR-302, April 1976. (AD A024485)

3. A. R. Vick, E. H. Andrews, J. S. Dennard and C. B. Craidon, "Comparison of Experimental Free-Jet Boundaries with Theoretical Results Obtained with the Method-of-Characteristics," NASA Technical Note D-2327, June 1964. (NTIS N64-23032)

4 L. Landau, and E. M. Lifshitz, Fluid Mechanics, Pergamon Press, 1959, pp 330-357.

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